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ANALYSIS OF HIGH TEMPORAL AND SPATIAL OBSERVATIONS OF HURRICANE JOAQUIN DURING TCI-15

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NASA WB57 flight crews and support team

Yankee High Density Sounding System (HDSS) team

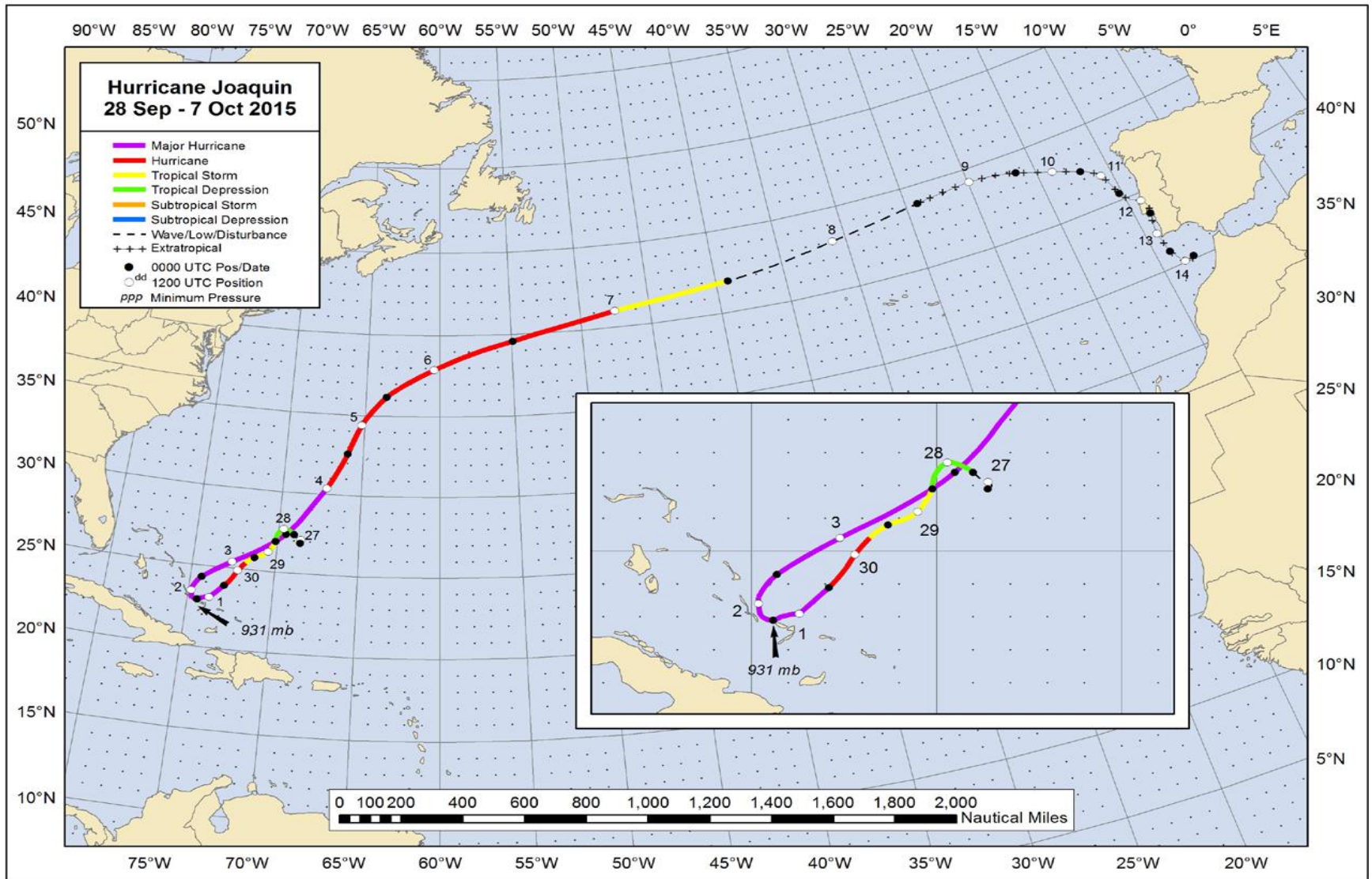
TCI leadership and mission support team

TCI Data quality assurance team

OBJECTIVES

- Provide an example of why analysis of high density soundings across Hurricane Joaquin also require highly accurate center positions
- Describe technique for calculating 3-D zero-wind center positions from the highly accurate GPS positions of sequences of High-Density Sounding System (HDSS) soundings as they fall from 10 km to the ocean surface
- Illustrate the vertical tilt of the vortex above 4-5 km during two center passes through Hurricane Joaquin on 4 October 2015

BEST-TRACK FOR HURRICANE JOAQUIN (2015)



NHC BEST-TRACK FILE FOR HURRICANE JOAQUIN, 3-7 October 2015

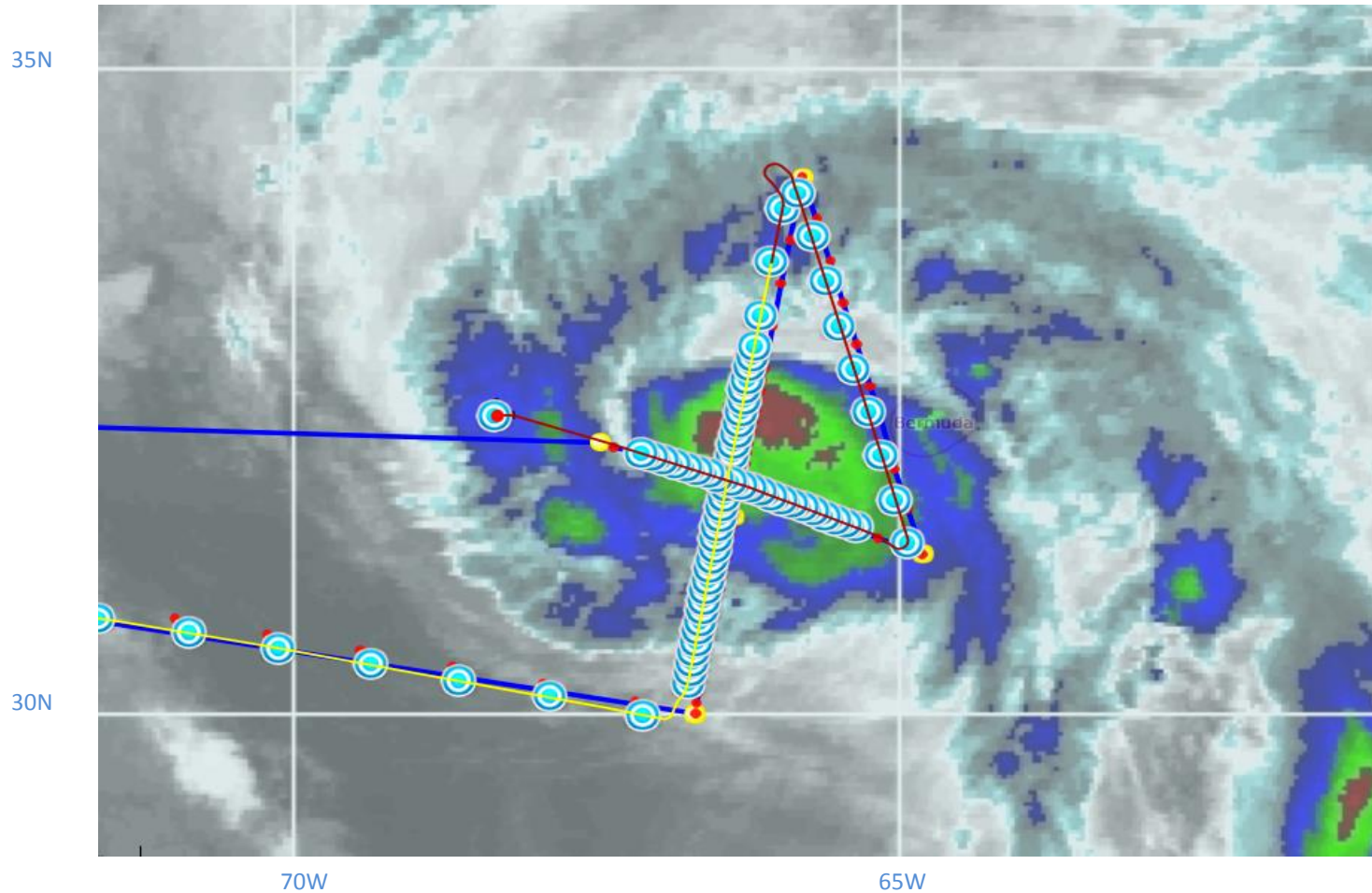
Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Translation Heading/ Speed (kt)
03/0000	24.3	74.3	943	115	51.7° / 8.1
03/0600	24.8	73.6	945	120	56.3° / 10.9
03/1200	25.4	72.6	934	135	57.6° / 17.0
03/1800	26.3	71.0	934	130	50.2° / 17.3
04/0000	27.4	69.5	941	115	34.9° / 18.4
04/0600	28.9	68.3	949	105	32.2° / 17.8
04/1200	30.4	67.2	956	95	26.4° / 13.4
04/1800	31.6	66.5	958	85	22.8° / 10.9
05/0000	32.6	66.0	961	75	18.4° / 10.6
05/0600	33.6	65.6	964	75	22.4° / 18.6
05/1200	34.4	65.2	964	75	32.3° / 10.7
05/1800	35.3	64.5	964	75	38.8° / 11.6
06/0000	36.2	63.6	967	75	52.1° / 13.1
06/0600	37.0	62.3	970	75	58.6° / 17.5
06/1200	37.9	60.4	974	70	63.7° / 20.9
06/1800	38.8	58.0	974	70	70.6° / 25.3
07/0000	39.6	54.9	974	70	

HDSS SONDE DROPS in HURRICANE JOAQUIN 4 October 2015*

Center crossings: South-to-North ~ 1800 UTC; East-to-West ~ 1900 UTC

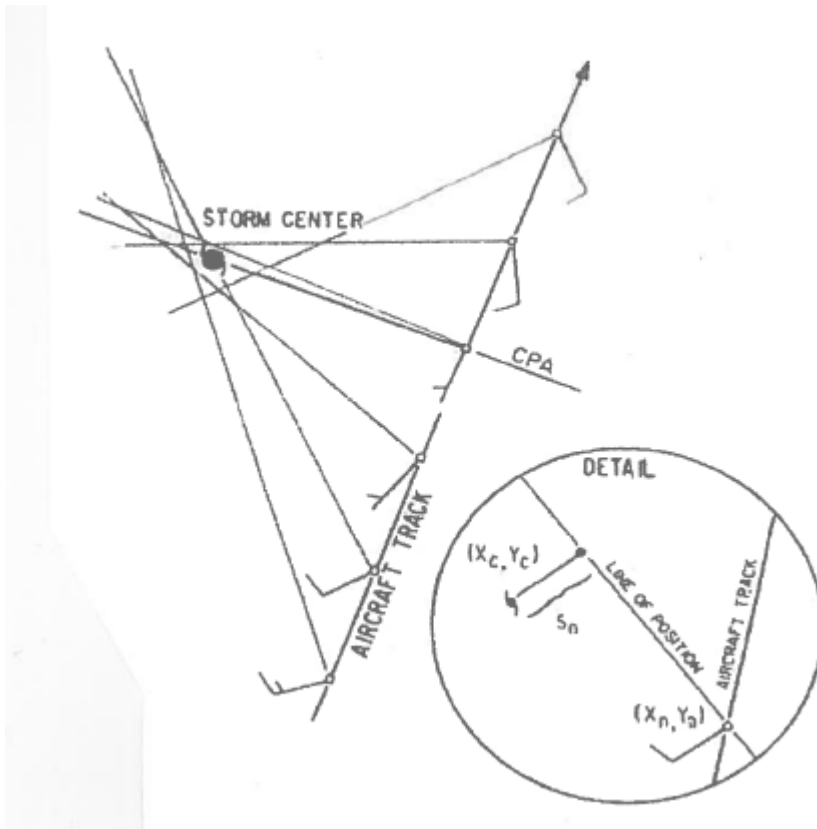
Sondes deployed ~ 42 sec (~ 4.67 miles) during two center crossings

Require accurate center positions for storm-relative positions of HDSS observations



* GOES IR image is at 1915 UTC

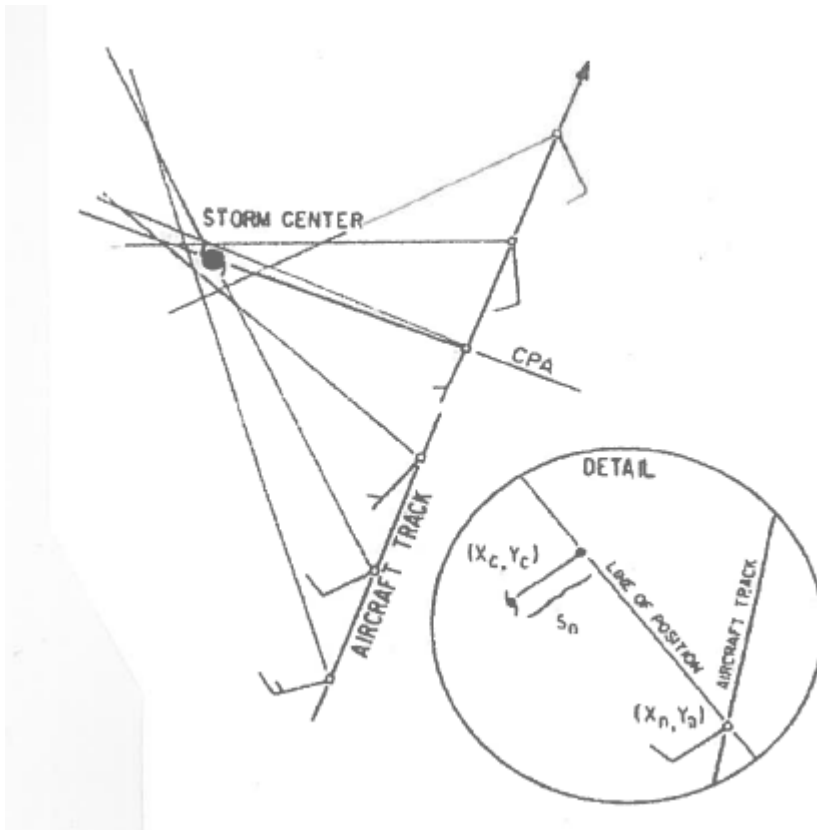
WILLOUGHBY AND CHELMOW (1982) CENTER LOCATION TECHNIQUE - AIRCRAFT



- Utilize flight-level wind directions at maximum temporal resolution (~ 1 sec; approximately 100 m) while the aircraft passes through the eye
- Lines of positions (or bearings) perpendicular to wind directions intersect to accurately locate the zero-wind center position

- Dynamic center (zero wind speed versus minimum pressure height or visual satellite center) must exist in any closed vortex
- Assumes gradient wind balance and neglects divergent component of the wind relative to the rotational component

FACTORS TO BE CONSIDERED IN USING HDSS SONDES WITH WILLOUGHBY AND CHELMOW (1982) TECHNIQUE FOR HIGHLY ACCURATE STORM CENTER POSITIONS



Consider these seven vector wind directions are to be extracted at specific elevations from seven HDSS soundings deployed from the NASA WB57 aircraft overflying the tropical cyclone center at 60,000 ft at a speed of 400 mph

HDSS sondes are deployed at ~42 sec intervals (~ 4.67 miles) and fall to the ocean surface in ~700 sec (11.67 minutes).

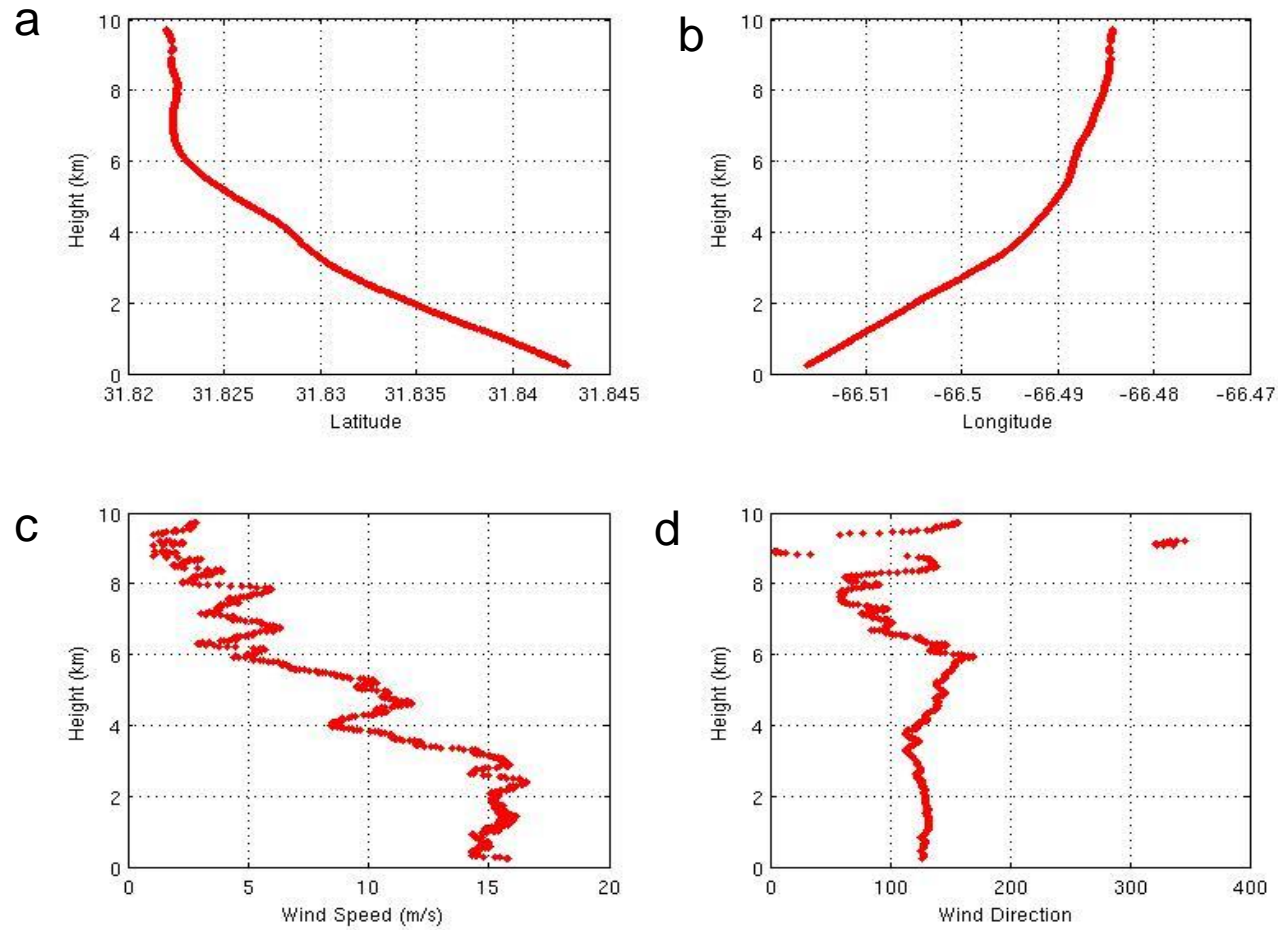
However, the sondes drift with the local winds at each elevation so their lat./long. positions are not directly below the deployment positions along WB57 aircraft track

- In addition to capability for high frequency drops, HDSS provides highly accurate GPS lat./long. positions at each elevation for these wind direction determinations
- During this sequence of seven sonde deployments over 294 sec and the sondes taking ~ 700 sec to fall to the surface, the TC center will have moved as well

CRITICAL REQUIREMENTS FOR HIGHLY ACCURATE GPS LAT/LONG WITH HDSS

HDSS sonde deployed at 1800 UTC 4 October during first overpass of Hurricane Joaquin eye

Northward (panel a) and westward (panel b) drift off of vertical profile

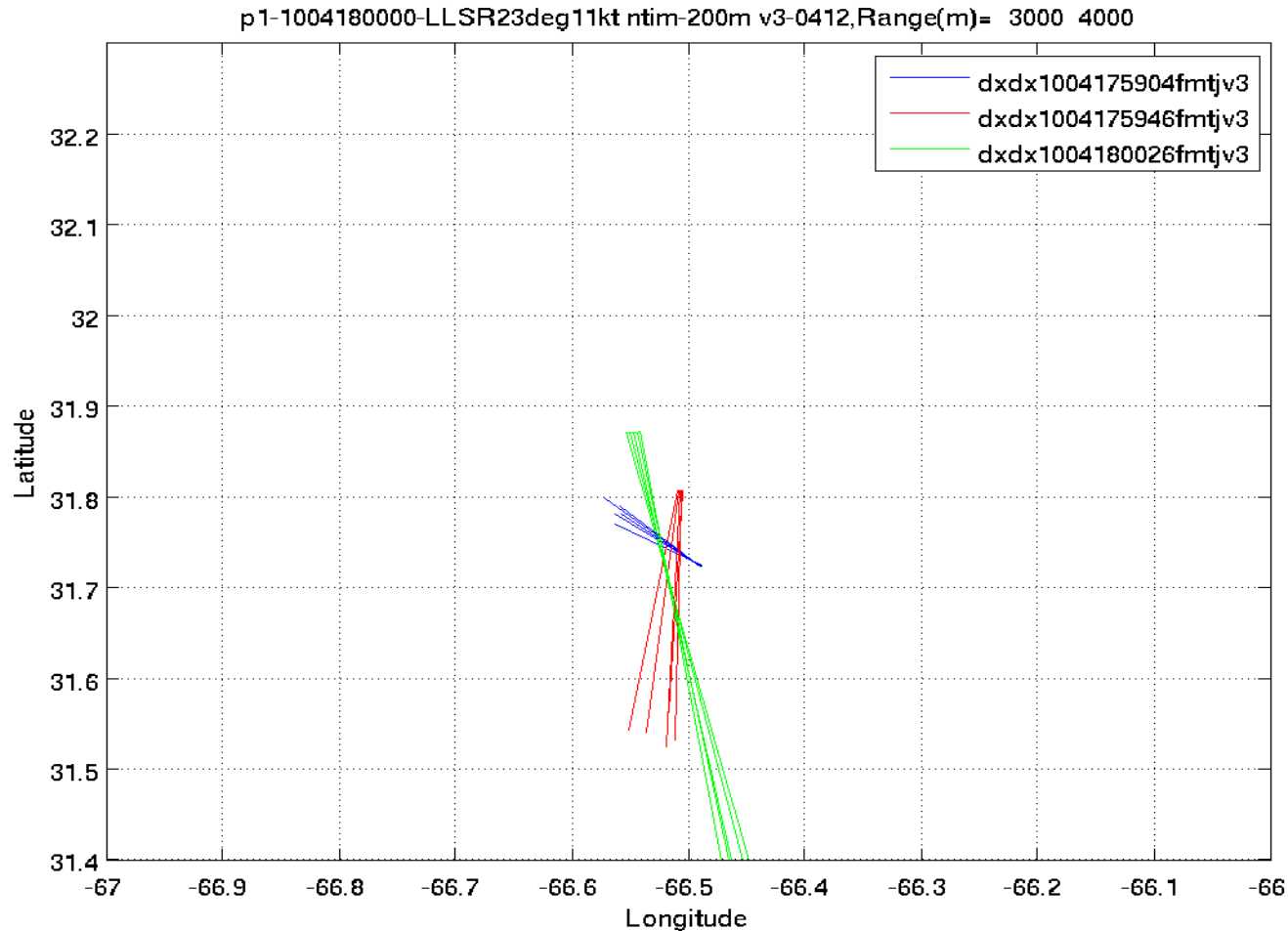


- Wind speeds every second are small above 6 km within the eye, but increase in outer region of eye
- Wind directions (and thus bearings) constant at 120 deg below 4 km indicate ZWC is to west-southwest

INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS AVERAGE WIND DIRECTIONS OVER 1 KM BASED ON GPS LAT/LONG POSITIONS

OVERPASS 1 WITH ZWC IN 3-4 KM LAYER

- Bearings from 1 km layer-average wind directions overlapping at 200 m in the vertical
- Lengths of bearing lines are proportional to wind speed



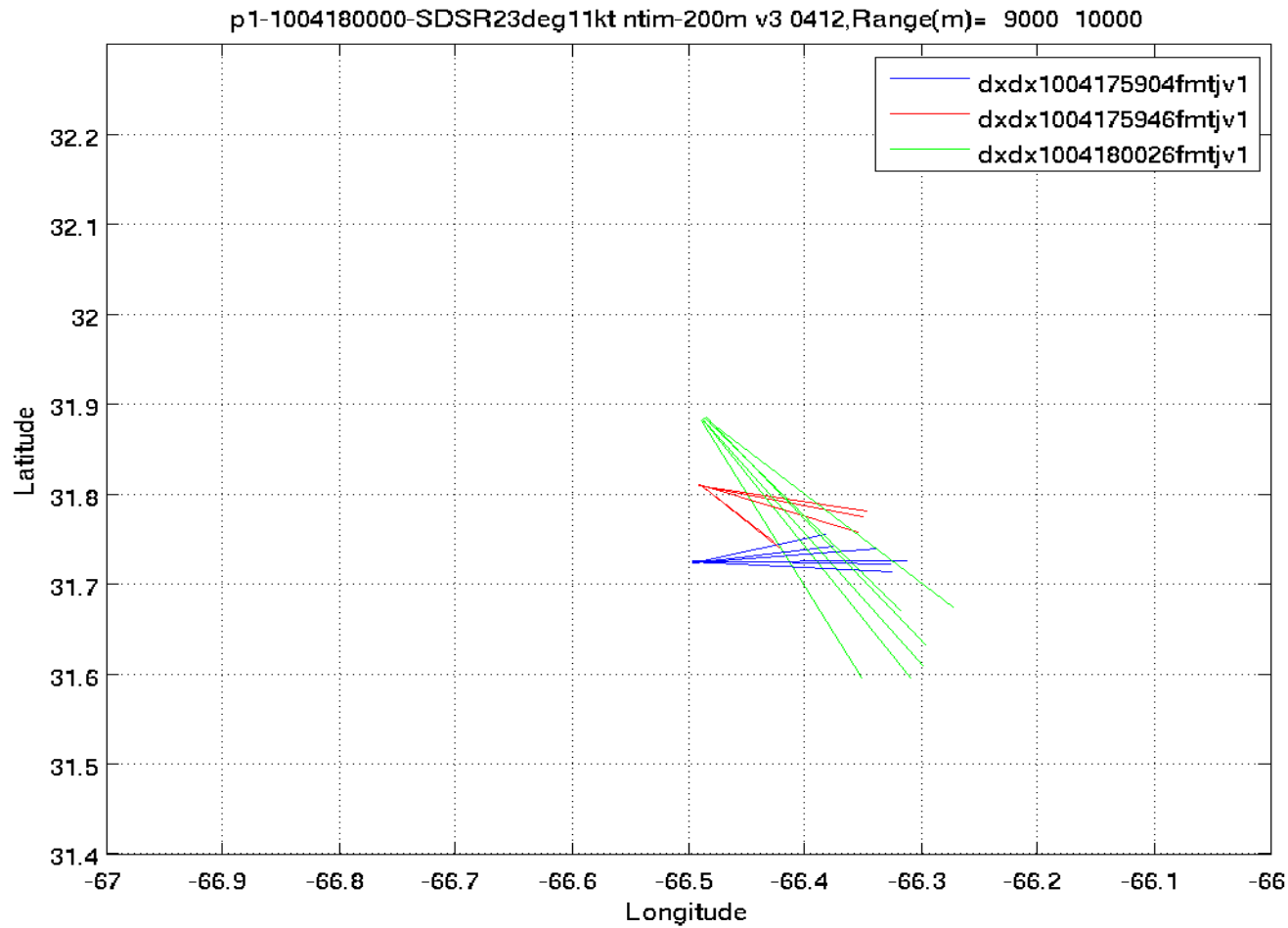
3.5 km ZWC at 31.75°N, 66.52°W vs HIRAD surface center 31.69°N, 66.58°W

*AMS 32nd Conference on Hurricanes and Tropical Meteorology,
17-22 April 2016, San Juan Puerto Rico*

INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS AVERAGE WIND DIRECTIONS OVER 1 KM BASED ON GPS LAT/LONG POSITIONS

OVERPASS 1 WITH ZWC IN 9-10 KM LAYER

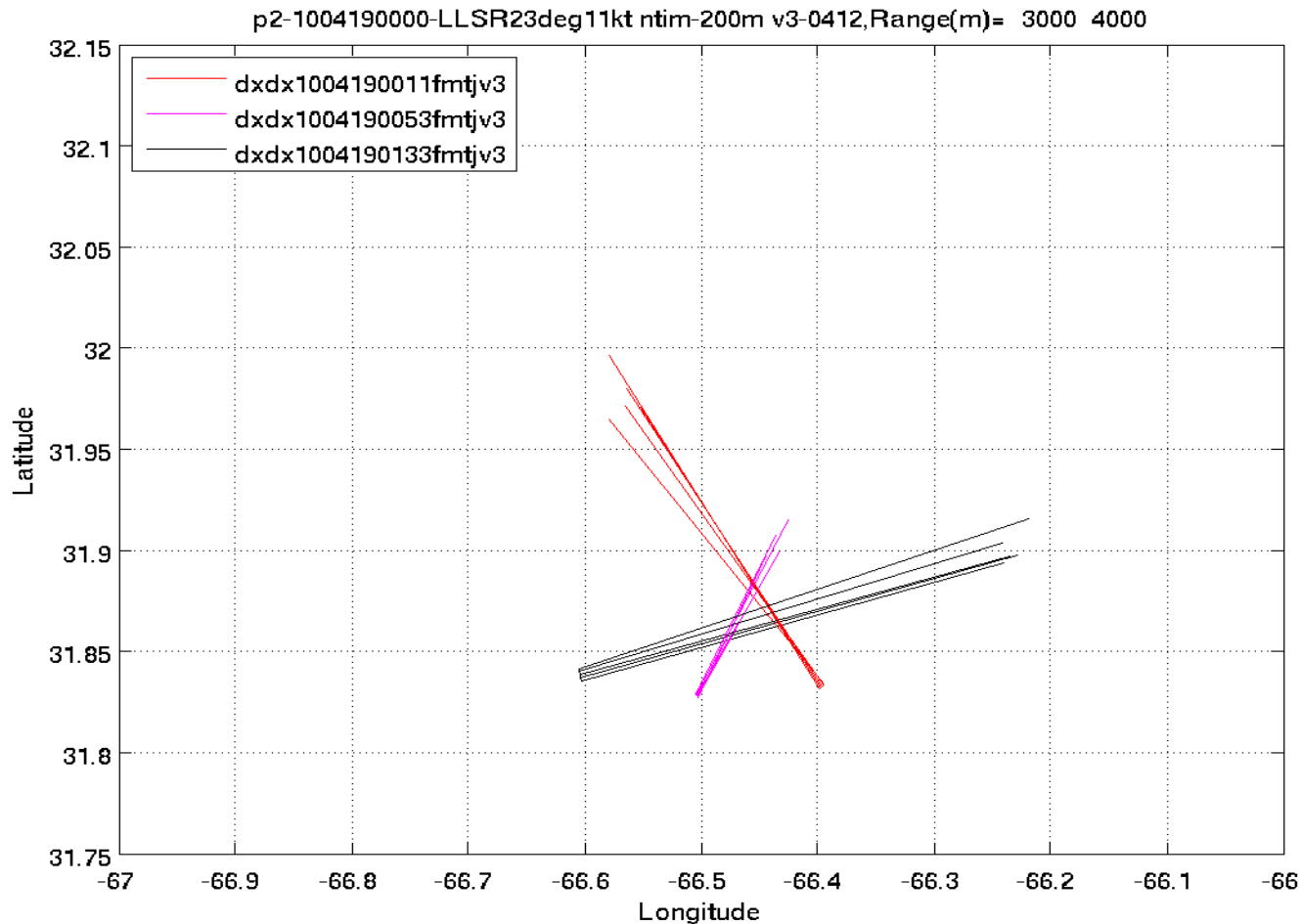
- Bearings from 1 km layer-average wind directions overlapping at 200 m in the vertical
- Lengths of bearing lines are proportional to wind speed



INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS AVERAGE WIND DIRECTIONS OVER 1 KM BASED ON GPS LAT/LONG POSITIONS

OVERPASS 2 WITH ZWC IN 3-4 KM LAYER

- Bearings from 1 km layer-average wind directions overlapping at 200 m in the vertical
- Lengths of bearing lines are proportional to wind speed

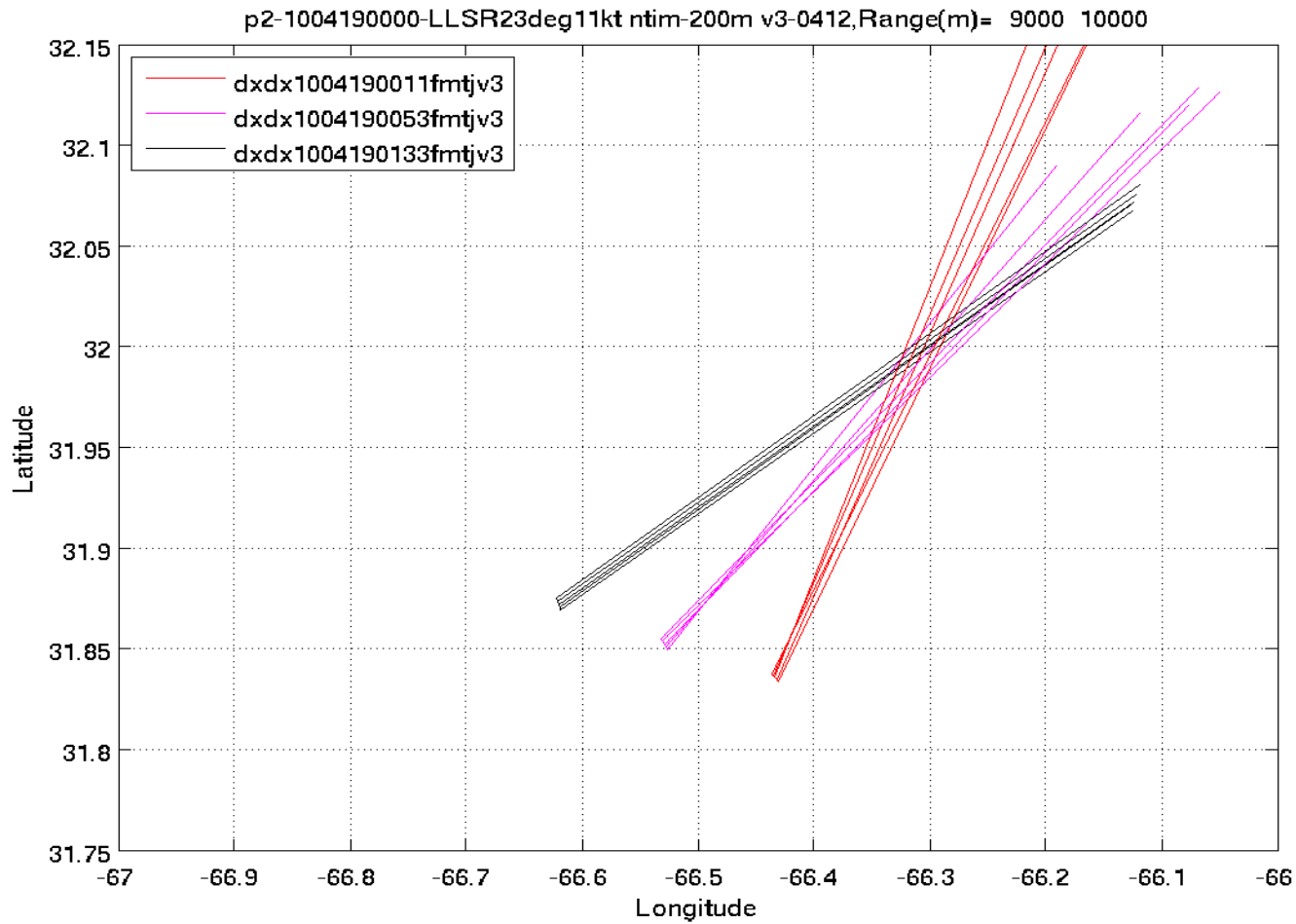


3.5 km ZWC at 31.87°N, 66.46°W vs HIRAD surface center 31.87°N, 66.53°W

INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS AVERAGE WIND DIRECTIONS OVER 1 KM BASED ON GPS LAT/LONG POSITIONS

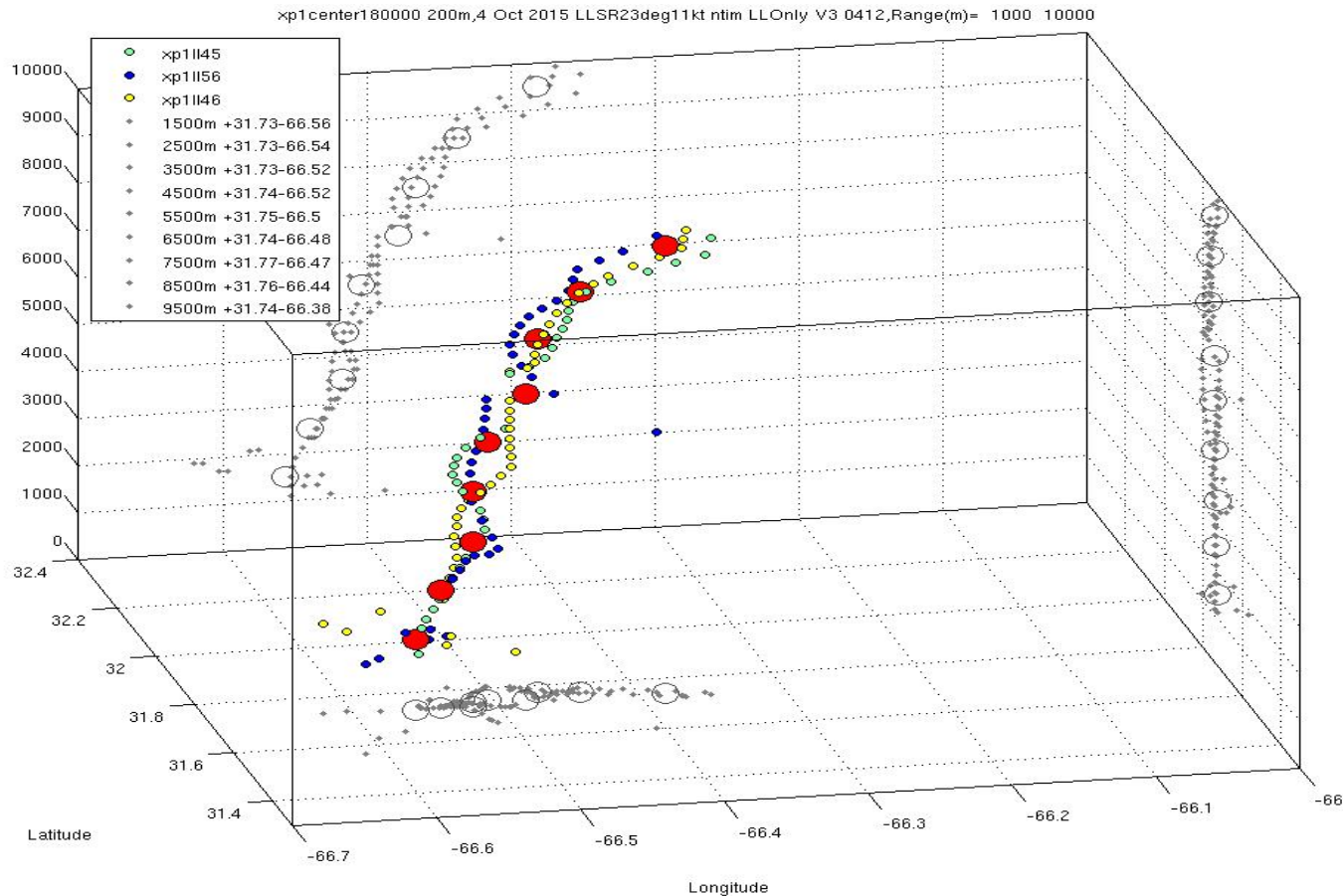
OVERPASS 2 WITH ZWC IN 9-10 KM LAYER

- Bearings from 1 km layer-average wind directions overlapping at 200 m in the vertical
- Lengths of bearing lines are proportional to wind speed



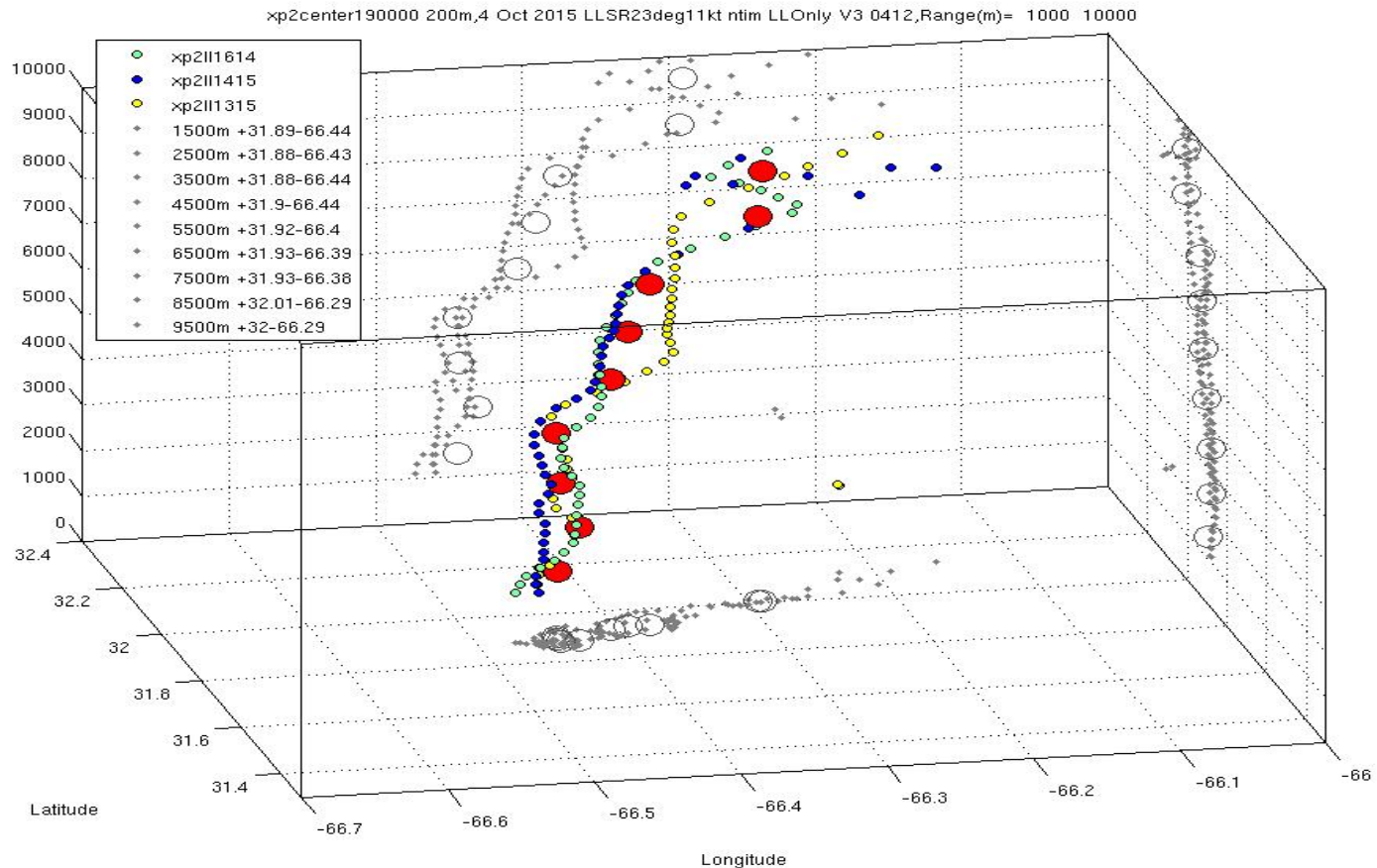
VORTEX TILT BETWEEN 1 KM AND 10 KM FROM **OVERPASS 1** HDDS WIND DIRECTIONS OVER 1 KM BASED ON GPS LAT/LONG POSITIONS

- Large red circles indicate ZWCs at one kilometer spacing based on consensus of 3 pairings of HDDS sondes (small colored circles) at 200 m spacing
- Tilt from 1.5 km to 6.5 km is 62 degrees and between 7.5 km and 9.5 km is 80 degrees



VORTEX TILT BETWEEN 1 KM AND 10 KM FROM **OVERPASS 2** HDDS WIND DIRECTIONS OVER 1 KM BASED ON GPS LAT/LONG POSITIONS

- Large red circles indicate ZWCs at one kilometer spacing based on consensus of 3 parings of HDDS sondes (small colored circles) at 200 m spacing
- Tilt from 1.5 km to 6.5 km is 52 degrees and between 7.5 km and 9.5 km is 80 degrees

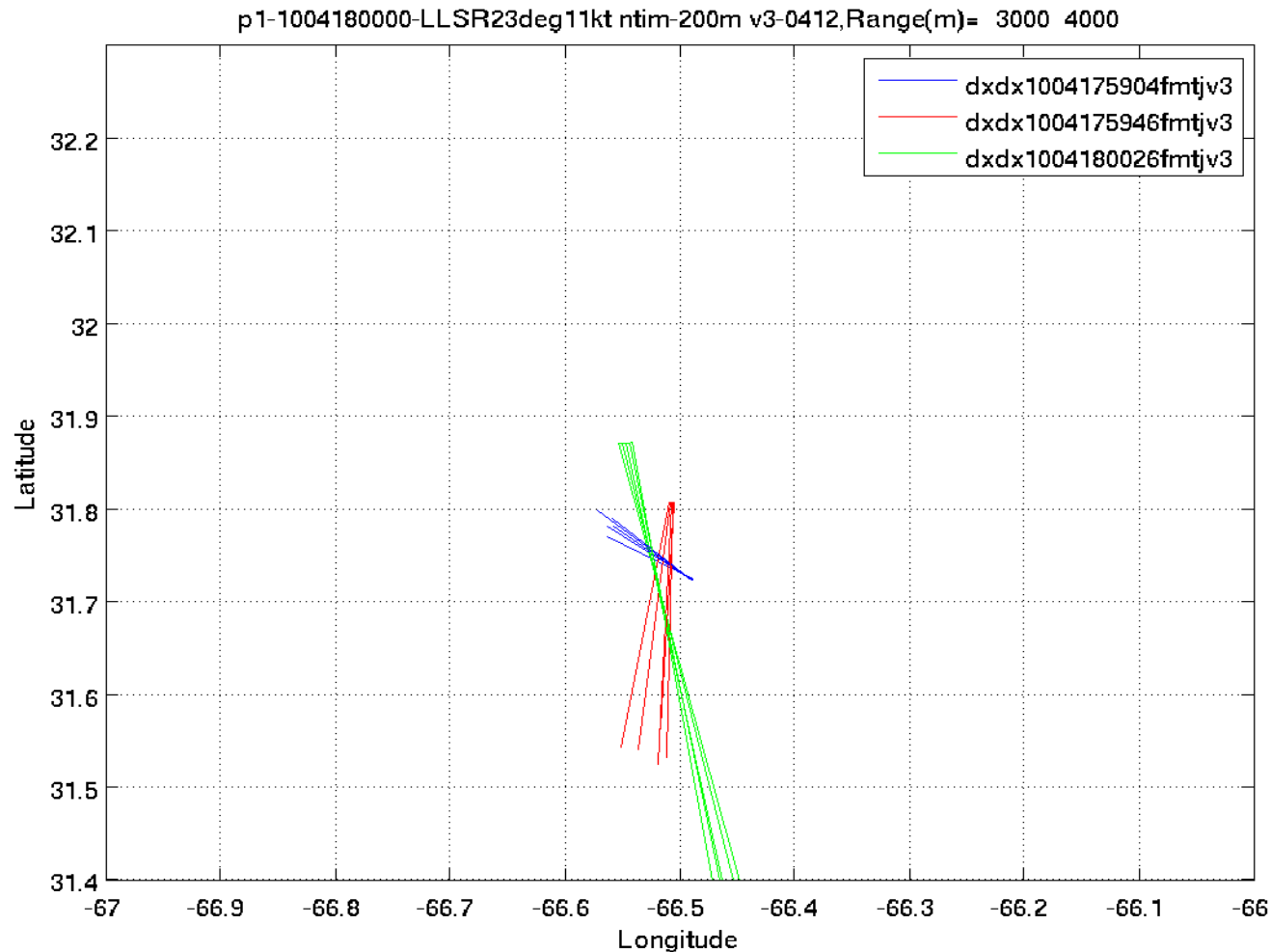


SUMMARY

- HDSS sondes deployed from NASA WB57 flying at 60,000 ft provide new opportunities to observe the three-dimensional structure of tropical cyclones
 - High temporal resolution HDSS observations require high accuracy zero-wind center (ZWC) positions for storm-relative positioning
- High accuracy ZWC positions may be derived as in Willoughby and Chelmow (1982) due to
 - GPS lat./long. positions accounting for HDSS drift as sonde falls
 - GPS lat./long. position differences to define an average wind direction over 1 km layers
- Vortex tilts between 1 km and 10 km of Hurricane Joaquin on 4 October 2015 are only one demonstration of new capability of the HDSS to observe tropical cyclone structure
 - Further comparisons with HIRAD surface positions
 - Comparisons with high temporal resolution CIMSS AMVs
 - Dynamic initialization for ingesting HDSS observations

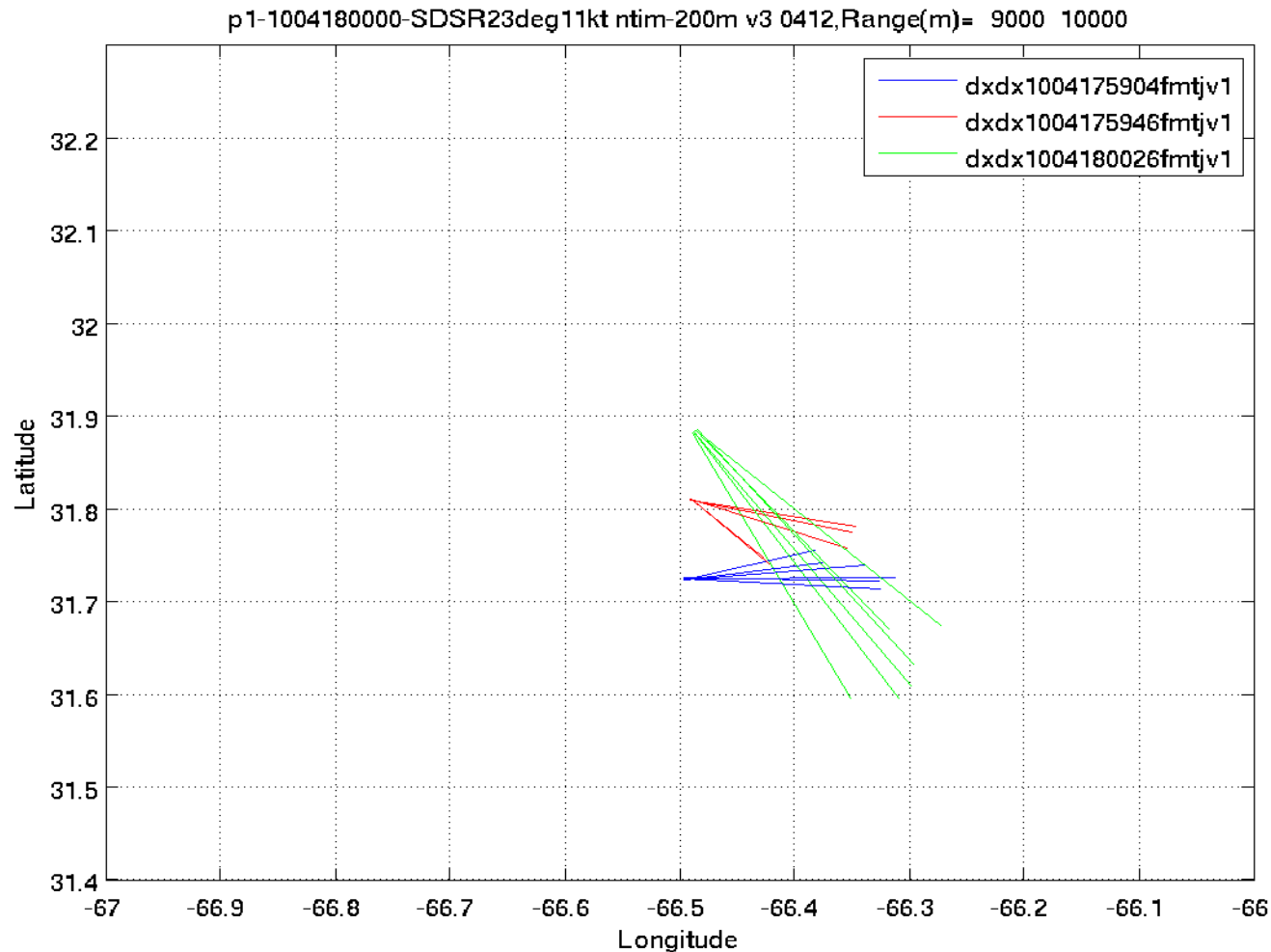
INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS WIND DIRECTIONS AVERAGED OVER 1 KM LAYERS, OVERLAPPED BY 200 M OVERPASS 1 WITH ZWC IN 3-4 KM LAYER

- Lengths of bearing lines are proportional to wind speed



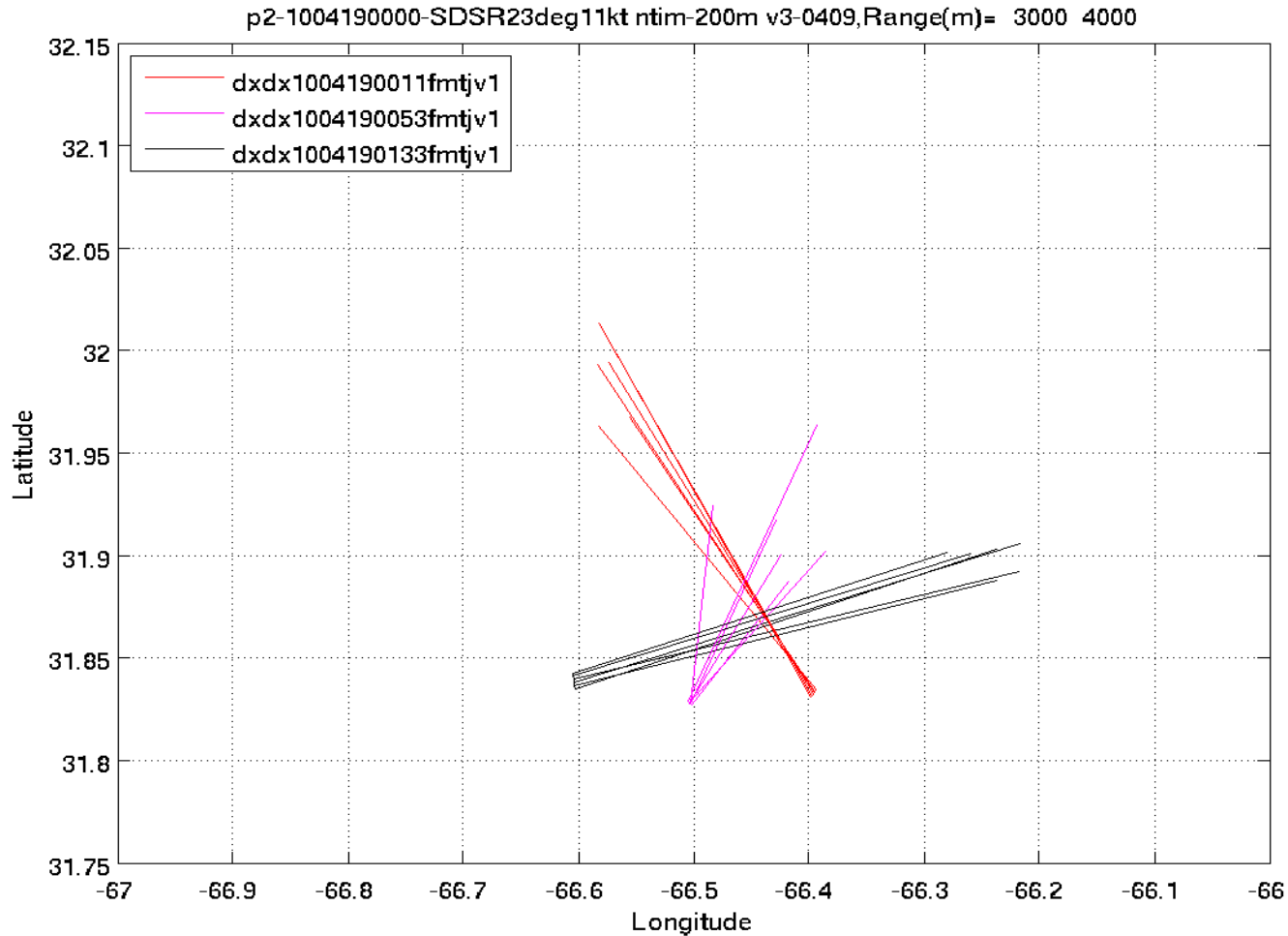
INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS WIND DIRECTIONS AVERAGED OVER 1 KM LAYERS, OVERLAPPED BY 200 M OVERPASS 1 WITH ZWC IN 9-10 KM LAYER

- Lengths of bearing lines are proportional to wind speed



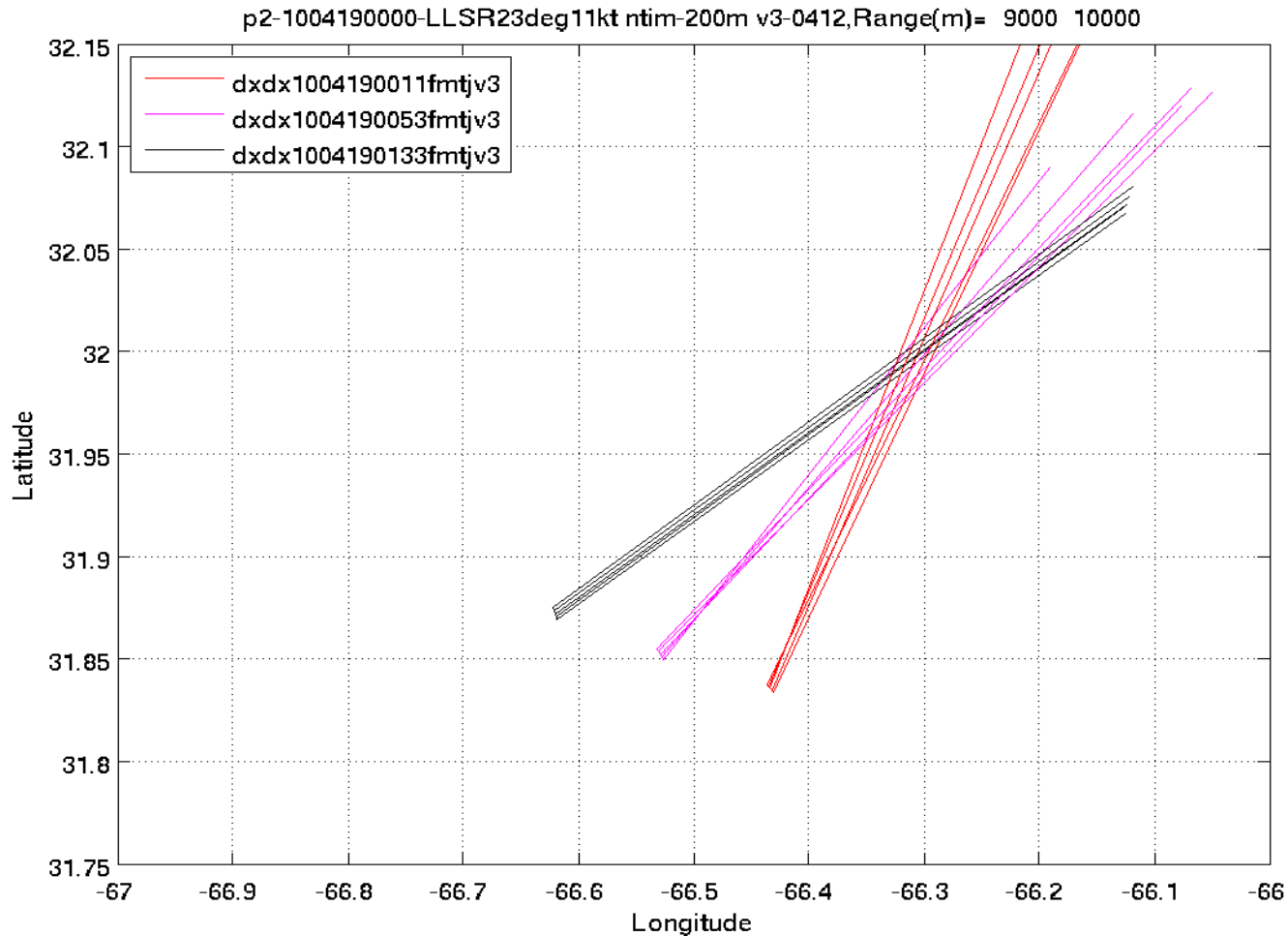
INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS WIND DIRECTIONS AVERAGED OVER 1 KM LAYERS, OVERLAPPED BY 200 M OVERPASS 2 WITH ZWC IN 3-4 KM LAYER

- Lengths of bearing lines are proportional to wind speed



INTERSECTIONS OF BEARINGS FROM PAIRS OF HDSS WIND DIRECTIONS AVERAGED OVER 1 KM LAYERS, OVERLAPPED BY 200 M **OVERPASS 2 WITH ZWC IN 9-10 KM LAYER**

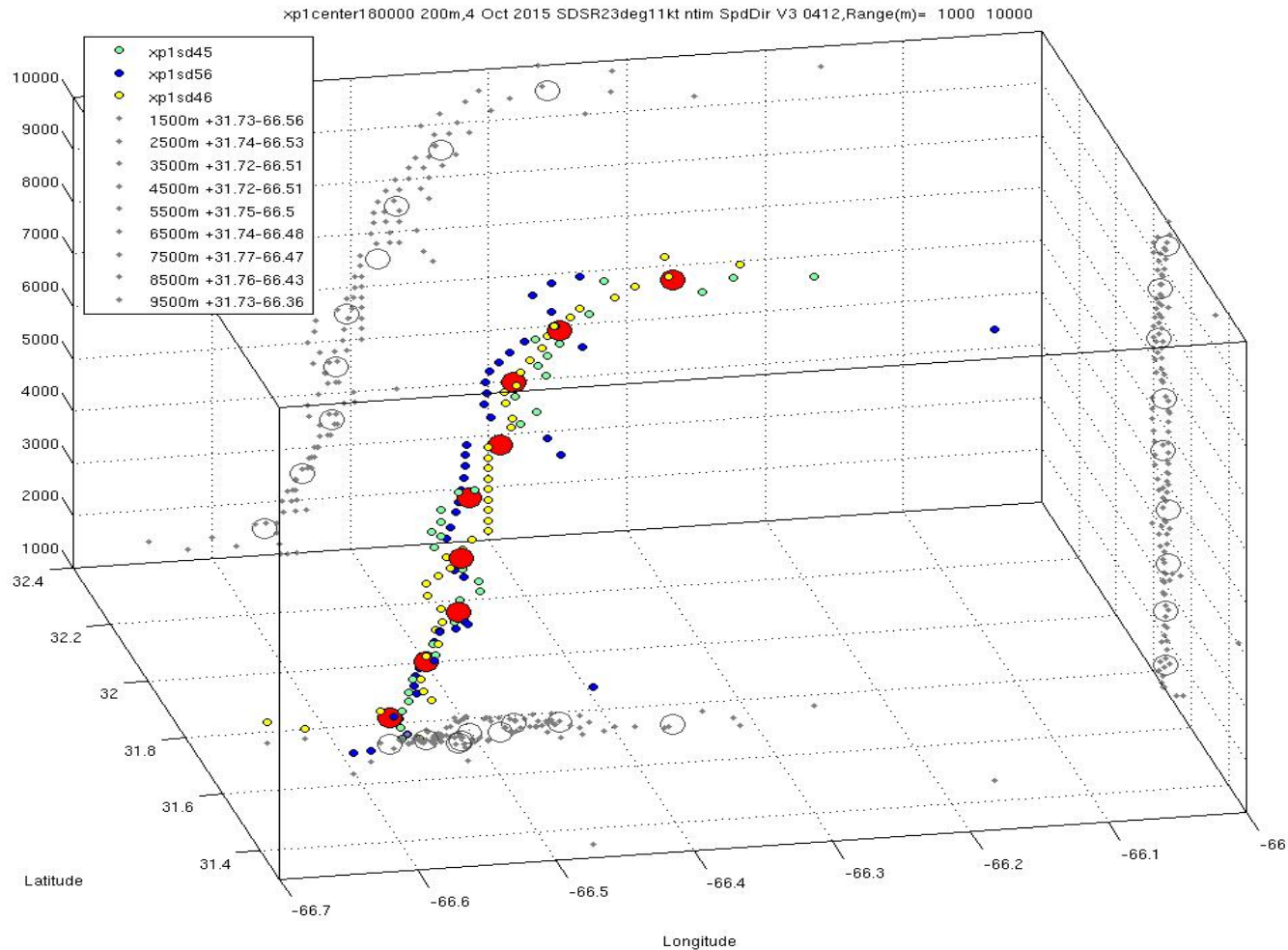
- Lengths of bearing lines are proportional to wind speed



VORTEX TILT BETWEEN 1 KM AND 10 KM FROM **OVERPASS 1** HDSS

WIND DIRECTIONS AVERAGED OVER 1 KM LAYERS

- Lengths of bearing lines are proportional to wind speed



VORTEX TILT BETWEEN 1 KM AND 10 KM FROM **OVERPASS 2** HDSS

WIND DIRECTIONS AVERAGED OVER 1 KM LAYERS

- Lengths of bearing lines are proportional to wind speed

